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(पहला पुनरीक्षण)

Indian Standard

EXPRESSION OF THE PERFORMANCE OF ELECTRICAL AND ELECTRONIC MEASURING EQUIPMENT

(First Revision)

ICS 17.220.20

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Price Group 5

Electronic Measuring Instruments, Systems and Accessories Sectional Committee, LTD 21

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Electronic Measuring Instruments, Systems and Accessories Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

This standard provides methods for ensuring uniformity in the specification and measurement of errors of equipment within its scope. All other necessary requirements have been reserved for relevant Indian Standards pertaining to particular types of equipment which fall within the scope of this standard.

This standard is largely based on IEC 359 (1987) 'Expression of the performance of electrical and electronic measuring equipment' issued by the International Electrotechnical Commission (IEC). The International Standards referred in the original IEC publication have been replaced by the corresponding Indian Standards.

The revision of this standard has been taken up to include the procedure for compliance testing and to align it with the latest international practices.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

EXPRESSION OF THE PERFORMANCE OF ELECTRICAL AND ELECTRONIC MEASURING EQUIPMENT

(First Revision)

1 SCOPE

This standard applies to the specification of the performance of the following kinds of electrical and electronic equipment and instruments and the accessories used with them:

a) Those which measure electrical quantities (indicating and recording instruments).

b) Those which supply measured electrical quantities (supply instruments), such as signal generators and some power supplies.

c) Those which measure non-electrical quantities using electrical means, excluding any parts, such as transducers, which provide an electrical analogue of the non-electrical quantity; and provided that there exists no relevant Indian Standard relating to the equipment or its electrical or electronic parts which has requirements that contradict this standard. The expression of performance covers only the electrical or electronic part.

2 REFERENCE

The following Indian Standard contains provision which through reference in this text, constitutes provision of this standard. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below.

IS No.	*Title*
9001 (Part 1) : 1988	Basic environmental testing procedures for electronic and electrical items: Part 1 General

3 TERMINOLOGY

3.1 For the purpose of this standard, the following definitions shall apply.

3.1.1 *True Value*

The value which characterizes a quantity perfectly defined, in the conditions which exist when that quantity is considered.

NOTE — The true value of a quantity is an ideal concept and, in general, cannot be known exactly.

3.1.2 *Conventional True Value*

A value approximating to the true value of a quantity such that, for the purpose for which that value is used, the difference between the two values can be neglected.

NOTES

1 The conventional true value of a quantity is generally determined by means of methods and by the use of instruments of an accuracy suitable for each particular case.

2 Since the true value cannot be known exactly, for the sake of simplicity and where no ambiguity exists, the term 'true value' may be used when 'conventional true value' is meant.

3.1.3 *Fiducial Value*

A clearly specified value to which reference is made in order to define the fiducial error.

NOTE — This value can be, for example, the measured value, the upper limit of the measuring range, the scale range, a preset value, or another clearly stated value.

3.1.4 *Rated Value*

A quantity value assigned by a manufacturer for a specified operating condition of the equipment or instrument.

3.1.5 *Range*

Domain between limits expressed by stating the values of the lower and upper limits of the quantity under consideration.

NOTE — The term 'range' is usually used with a modifier. It may apply to a performance characteristic, to an influence quantity, etc.

3.1.6 *Performance*

The degree to which the intended functions of an instrument are accomplished.

3.1.7 *Performance Characteristic*

One of the quantities (described by values, tolerances, ranges) assigned to an equipment in order to define its performance.

NOTES

1 Depending on its application, one and the same quantity may

be referred to in this standard as a 'performance characteristic' and as a 'measured or supplied quantity', and also may act as an 'influence quantity'.

2 In addition, the term 'performance characteristic' includes quotients of quantities, such as, voltage per unit of length.

3.1.8 *Influence Quantity*

A quantity which is not the subject of the measurement but which influences the value of the measured quantity or the indication of the measuring equipment.

NOTES

1 An influence quantity may be external or internal with reference to the equipment.

2 When the value of one performance characteristic changes within its measuring range, it may affect the error due to another.

3 The measured quantity or a parameter of it may itself act as an influence quantity. For example, for a voltmeter, the value of the measured voltage may produce an additional error due to non-linearity or its frequency may also cause an additional error.

3.1.9 *Reference Conditions*

The appropriate set of influence quantities and performance characteristics, with reference values with their tolerances and reference ranges, with respect to which the intrinsic error is specified.

3.1.10 *Reference Value*

A specified value of one of a set of reference conditions.

NOTE — A tolerance is specified for a reference value.

3.1.11 *Reference Range*

A specified range of values of one of a set of reference conditions.

3.1.12 *Rated Operating Conditions*

A set of specified measuring ranges for performance characteristics and specified operating ranges for influence quantities, within which the variations or operating errors of an instrument are specified and determined.

3.1.13 *Specified Operating Range*

A range of values of a single influence quantity which forms a part of the rated operating conditions.

NOTE —The operating range is a concept similar to the 'nominal range of use' and 'rated range of use'.

3.1.14 *Specified Measuring Range*

The set of values of a measured quantity for which the error of a measuring instrument is intended to lie within specified limits.

NOTES

1 An instrument can have several specified measuring ranges.

2 The specified measuring range may be smaller than the range of values indicated.

3 This term used to be known as 'effective range'.

3.1.15 *Limiting Conditions*

The extreme conditions which an operating measuring instrument can withstand without damage and without degradation of its metrological characteristics when it is subsequently operated under its rated operating conditions.

3.1.16 *Storage and Transport Conditions*

The extreme conditions which a non-operating measuring instrument can withstand without damage and without degradation of its metrological characteristics when it is subsequently operated under its rated operating conditions.

3.1.17 *(Absolute) Error (of a Measuring Instrument)*

The indication of a measuring instrument minus the (conventional) true value of the measured quantity.

NOTE — For a supplied quantity, the indication is its nominal or marked value.

3.1.18 *Relative Error*

The ratio of the error (expressed in their units of the measured or supplied quantity) to the conventional true value.

3.1.19 *Fiducial Error*

The error of a measuring instrument divided by the fiducial value specified for the instrument.

3.1.20 *Intrinsic Error*

The error of a measuring instrument or supply instrument when used under reference conditions.

NOTE—Error caused by friction is a part of the intrinsic error.

3.1.21 *Variation*

The difference between the indicated values for the same value of the measured quantity of an indicating or recording instrument, or the (conventional) true values of a supply instrument, when a single influence quantity assumes successively two different values.

3.1.22 *Operating Error*

The error of a performance characteristic which is obtained at any point within the rated operating conditions.

NOTE—The operating error will have an extreme value (without regard to sign) at some combination of values of influence quantities within their operating ranges.

3.1.23 *Limits of Error*

The two extreme values (positive and negative) of error assigned by the manufacturer to equipment operating under specified conditions.

4 QUANTITIES, VALUES AND RANGES TO BE STATED AND MEASURED

4.1 In the manufacturer's technical specification for measuring equipment, the quality of performance is defined by statements on the limits of error of the performance characteristics.

A specification of limits of error provides one of the following kinds of information:

a) Limits of intrinsic error and variations.
b) Limits of operating error, calculated from (a), using statistical methods.
c) Worst-case error, calculated from (a).

4.2 A reference value or reference range and an operating range are defined for each influence quantity which the manufacturer takes into account. It is also useful to specify the limiting conditions and storage and transport conditions of each influence quantity.

4.3 Determination of limits of error is based on the measurement of intrinsic errors and variations, followed by any necessary calculations.

4.4 Where limits of operating error are specified, the recommended method of measurement and calculation provides a probability of 95 percent that the error will remain within the limits during use within the rated operating conditions (*see* Annex A).

4.5 The manufacturer's responsibility relates to the correction of excessive operating errors and worst-case errors, which are calculated from intrinsic errors and variations inside their stated limits, but he is not responsible for injury or defects resulting from these excesses.

5 REQUIREMENT OF RELEVANT INDIAN STANDARDS

5.1 The relevant Indian Standards covering all kinds of equipments falling within the scope of this standard shall observe the rules laid down herein and especially the following points:

a) A relevant Indian Standard shall call for particular specifications to include the relevant performance characteristics and influence quantities, as well as the type of information (*see* **7.3**) used in specifying limits of error. It should also include the limiting conditions and the storage and transport conditions.
b) A relevant Indian Standard shall not contradict any requirements of this standard.

6 PROCEDURE FOR STATEMENT

6.1 Statements on any performance characteristic shall be made on the basis of relevant Indian Standards. When the Indian Standards are not available the statements shall be made as indicated in this clause. In the latter case, the decision whether any statement is made on a particular performance characteristic and how it is presented is left to the discretion of the manufacturer.

6.2 Statement of Values and Ranges

6.2.1 The manufacturer shall state rated values or specified measuring ranges for all quantities which he considers to be performance characteristics applicable to the particular equipment.

6.2.2 The manufacturer shall state a reference value or a reference range and/or a specified operating range for each influence quantity which he takes into account when specifying limits of error of performance characteristics. The specified operating range shall include the whole of the reference range and usually exceeds it in at least one direction.

If any performance characteristic acts as an influence quantity, its measuring range is its specified operating range.

If any performance characteristic appears as an influence quantity, its reference value or reference range shall also be stated unless this is the same as its specified measuring range.

For any influence quantity not specified, its reference value or reference range is considered to be its specified operating range.

The information on reference values and reference ranges for some common influence quantities for use in compliance testing is provided in **7.7**. The inclusion of these values or ranges in a technical specification is not mandatory.

NOTE — A variation may exceed its specified limit if the conditions under which the instrument is used include more than one stated influence quantity lying outside their reference values or ranges.

6.2.3 The manufacturer should specify limiting conditions and storage and transport conditions for each specified influence quantity. If no ranges are specified, the rated operating conditions are considered to be the limiting conditions and to include the storage and transport conditions.

6.3 Statement of Limits of Error

6.3.1 If there is a relevant Indian Standard which relates to the equipment, limits of errors of performance characteristics shall be specified in accordance with it.

6.3.2 For all other equipment, the specification of limits of error may give one of several types of information. These are described as Types A, B and C in **6.3.3** to **6.3.5**.

6.3.3 *Limits of Intrinsic Error and Variations (Type A)*

6.3.3.1 Limits of intrinsic error are specified with respect to reference conditions and limits of variations are specified with respect to rated operating conditions.

6.3.3.2 This method is usually realized by assigning an accuracy class to equipment whereby the limits are implicit in the classification.

6.3.4 *Limits of Operating Error (Type B)*

6.3.4.1 Limits of operating error are specified with respect to rated operating conditions. The limits are based on the stated limits of intrinsic error and variations, according to **6.3.3**. They are calculated so as to provide a stated probability that the error will remain within specified limits.

6.3.4.2 Annex A gives recommended calculation formulae which provide a value of 95 percent for this probability. If none of these formulae is used, then the manufacturer shall describe the method he uses, and state the value of this probability.

6.3.4.3 If this calculation results in a more pessimistic value than the worst-case error of **6.3.5**, then the worst-case error is chosen as the operating error. This may occur if the intrinsic error or one single variation is the chief cause of the result.

6.3.5 *Worst-Case Error (Type C)*

6.3.5.1 The worst-case error is specified with respect to the rated operating conditions, and based on the limits of intrinsic error and variations according to **6.3.3**.

6.3.5.2 To calculate the worst-case error, the moduli of the most unfavourable limit values of the intrinsic error and variations are added up arithmetically.

6.3.5.3 The result of this statement of worst-case error does not depend upon the rules of statistics. For nearly all conditions it does not represent the actual error and it is likely to be too pessimistic.

6.3.6 Where operating error or worst-case error are stated, intrinsic error and limits of variations may also be stated.

NOTE — When the intrinsic error and limits of variation are not stated, the manufacturer should provide them on request.

6.3.7 Several limits of operating error for one performance characteristic may be stated with respect to several stated sets of rated operating conditions.

6.3.8 Errors may be specified either in absolute terms or in relative terms. In some cases, one part of an error is expressed as a relative error whilst the other part of it is an absolute value, for instance ± (2% +20 mV). In this case, the calculation of an operating error according to **6.3.4** and the calculation of a worst-case error according to **6.3.5** is done separately for the relative parts and for the absolute parts of the intrinsic error and variations.

6.3.9 The value to which a relative error or fiducial error is referred shall be clearly stated. That same value shall be used when more than one limit of error is specified for a particular performance characteristic.

6.4 Choice of Influence Quantities

6.4.1 The smaller the limit of error, the more important it is to take care in choosing the influence quantities to be specified. For guidance, this clause describes the various kinds of influence quantities.

6.4.1.1 Influence quantities may lie outside or inside the measuring equipment. Those which lie outside the equipment are characteristics of the environment, the power supply or time.

Examples: Temperature, supply voltage, time elapsed since application of power.

6.4.1.2 Influence quantities which lie inside the equipment are of several kinds:

a) Signal parameters act as influence quantities.

   Example: The signal parameter 'frequency' influences the performance characteristic 'indicated voltage' of a voltmeter.

b) Other performance characteristics besides the one whose error is sought act as influence quantities.

   Examples: The performance characteristics 'integrating time, r.m.s. value, mean value, peak value' of a voltmeter influence the relevant performance characteristic 'indicated voltage'. Also the output power of a signal generator influences the performance characteristic 'frequency'.

c) The performance characteristic whose error is sought may itself be an influence quantity. This effect is caused by non-linearity outside the reference range but inside the measuring range.

   Example: The voltage measuring range of a digital multimeter is 1 mV to 1 000 V. Its reference value is stated 1 V. The performance characteristic 'indicated voltage' acts as its own influence quantity in the measuring range.

7 PROCEDURE FOR COMPLIANCE TESTING

7.1 General

7.1.1 Compliance testing consists of determining intrinsic errors and variations, followed by confirming that an instrument having these errors complies with the specified limits of error. Where relevant, the test methods of IS 9000 (Part 1) shall be used.

7.1.2 Only values with specified limits can be considered subject to testing. Values without limits are for information, and are subject to simple checking only.

7.1.3 If limits are specified, compliance tests shall be carried out under the conditions indicated in this clause.

7.2 Measurement of Intrinsic Errors and Variations

7.2.1 The intrinsic error of each specified performance characteristic shall be measured under reference conditions (*see* **7.7**).

7.2.2 The limits of the variations of each specified performance characteristic shall be measured. A variation of a performance characteristic is measured when an influence quantity assumes successively two different values within its operating range, as below:

a) When measuring the variation due to an influence quantity having a reference value, the error is first determined at the reference value of the influence quantity.

   The largest error at any point within the operating range (above or below the reference value) is then determined. The variation is the greatest of the differences (without regard to sign) between the error at the reference value and any other error within the operating range.

b) When measuring the variation due to an influence quantity having a reference range, the error is first determined at both limits of the reference range.

   The error is then determined at all points (above and below the reference range) within the operating range.

   The greatest difference (without regard to sign) between the error at one limit of the reference range and any other error within the adjacent part of the specified operating range is determined. The determination is repeated for that part of the specified operating range adjacent to the other limit of the reference range. The variation is taken as the greater of the two differences (without regard to sign) so determined (*see* diagrams 1 and 2 of Table 1).

   Where a performance characteristic acts as an influence quantity, the variation is taken with respect to the specified measuring range (*see* diagrams 3 and 4 of Table 1).

c) All influence quantities other than the one being tested are located within their reference conditions and are constant. The performance characteristic is located within its measuring range and is not intentionally varied.

d) For variations Table 2 summarizes the simple type and several complex types, and the conditions for measuring them.

7.2.3 Using the symbols of Annex A, it is usual to neglect any variations which follow the conditions:

$$\overline{T}_i = 0;\ |\ T_u - T_l\ |\ \le 0.2\ |\ E_u - E_l\ |$$

7.2.4 Intrinsic errors and variations are valid under steady-state conditions.

NOTE — The term 'steady state' applies to balance conditions after a sudden change of a quantity.

7.2.5 Intrinsic errors and variations ought to be statistically independent. It may be risky to assume that the effects of influence quantities are independent if the stresses induced by two of them add together, unless the effects are small. If the variations are comparable with the intrinsic error, it may be useful to make combined tests with both quantities at each of their limit values (*see* Annex A).

7.3 Confirmation of Compliance with Specified Limits of Error

In relation to the several types of information for specifying the limits of error which are described in **6.3**, the requirements which confirm that the error of a performance characteristic does not exceed the specified limits are shown below.

7.3.1 *For Specified Intrinsic Error and Variations (Type A)*

Measured intrinsic errors and variations shall lie within their stated limits.

7.3.2 *For Specified Operating Error (Type B)*

a) Measured intrinsic errors and variations shall lie within their stated limits, or
b) The operating error, measured at any combination of values of the influence quantities within their rated operating conditions, shall lie within its stated limits.

Procedures (a) and (b) are in principle equivalent, but procedure (b) is in most cases very expensive and sometimes impossible to carry out.

7.3.3 *For Specified Worst-Case Error (Type C)*

The measured intrinsic error and variations shall lie inside the limits used in the calculation (*see* **6.3.5**).

7.4 Testing for Environmental Damage

7.4.1 Tests shall be made to determine that the equipment satisfies the relevant statements concerning its performance under rated operating conditions, after being subjected to the following conditions for a specified time:

a) After operation with any number of specified influence quantities at any probable value within the limiting conditions.
b) After being subjected in a non-operating state to conditions in which any of the specified influence quantities assume any probable value within the storage and transport conditions.

7.4.2 After exposure, the equipment shall be inspected for defects in switches and other mechanical parts. Operation shall be checked for compliance with all specified performance requirements.

Table 1 Values and Ranges for Measurement of Variations

(*Clause* 7.2.2)

Diagram 1 : Where the influence quantity has a reference value

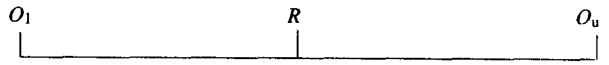


Diagram 2 : Where the influence quantity has a reference range

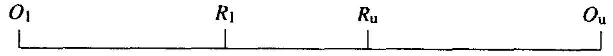


Diagram 3 : Where the performance characteristic has a reference value

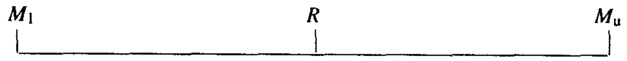
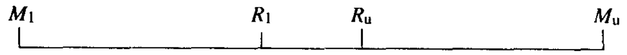


Diagram 4: Where the performance characteristic has a reference range



O_l = lower limit of the specified operating range
O_u = upper limit of the specified operating range
R = reference value, point of the first measurement
R_l = lower limit of the reference range, point of first measurement to determine variation in the range $M_l - R_l$
R_u = upper limit of the reference range, point of first measurement to determine variation in the range $M_u - R_u$
M_l = lower limit of the specified measuring range
M_u = upper limit of the specified measuring range

Table 2 Possible Types of Variation and the Effects Caused

(*Clause* 7.2.2)

Reason for the Variation	Effect
Type 1: Simple Variation	
Change of an influence quantity within the ranges $R - O_l$ and $R - O_u$ (diagram 1)* or $R_l - O_l$ and $R_u - O_u$ (diagram 2)* (*see* Note 1)	Change of indicated or supplied value of performance characteristic
Type 2 : Second-Order Variation	
Change of an influence quantity (as in Type 1 above) (*see* Note 2)	Change of a variation of another influence quantity (variation of a variation)
Type 3 Variation as a Combination of Types 1 and 2	
Simultaneous change of both influence quantities (*see* Note 3)	Sum of Types 1 and 2
Type 4: Variation by Non-Linearity	
Change of a performance characteristic in the range $R - M_l$ and $R - M_u$ (diagram 3)* or $R_l - M_l$ and $R_u - M_u$ (diagram 4)* (*see* Note 4)	Change of the relative error of indicated value of performance characteristic

NOTES

1 All other influence quantities are within the reference conditions and are constant. The performance characteristic is within its specified measuring range and is not intentionally varied. Any combination of these values are in their permitted ranges.

2 The influence quantity of the influenced variation is within its operating range. All other conditions as in Type 1.

3 The values of both of the influence quantities are varied simultaneously in order to determine the extreme value of the variation. All other conditions as in Type 1.

4 If influence quantities exist which influence the variation, these influence quantities are within their specified operating ranges and are constant. All other influence quantities are within their reference conditions and are constant. Any combination of all influence quantities are in their permitted ranges.

---

*The diagrams referred to in Table 2 will be found in Table 1.

7.5 Allowing for Effect of Test Equipment

7.5.1 In general, measurements shall be carried out with instruments which do not appreciably (or only calculably) affect the values to be measured. In principle, the errors in measurements made with these instruments should be negligible in comparison with the errors to be determined.

7.5.2 When the error of the instrument is not negligible, the following rules shall apply in order that a manufacturer does not deliver an instrument which has excessive errors and in order that a user does not reject an instrument which does not have excessive errors.

If the stated permissible error is $\pm e$ for a given performance characteristic and the error of the relevant testing method is $\pm n$, then;

- the manufacturer's limits of error shall be $\pm (e - n)$, and
- the user's limits of error shall be $\pm (e + n)$.

7.5.3 The quantity n should be as small as reasonably possible in relation to e. As the ratio between n and e approaches unity, a compromise becomes necessary between the high cost (and sometimes inconvenience of operation) of very accurate testing methods and the proportion of tested instruments whose accuracy is in doubt. Otherwise a manufacturer might reject and not deliver instruments which are satisfactory, or a user might accept instruments which are in fact not satisfactory.

7.5.4 A ratio of 1 : 10 for $n : e$ is preferable, and will usually enable n to be neglected. This wide ratio is often impracticable, due to cost or shortcomings of the available technology, and narrower ratios such as 1 : 4, 1 : 3 or 1 : 2 are sometimes all that can be achieved.

7.6 Conditions of Equipment Under Test

7.6.1 Before compliance tests on the equipment (including accessories, if any), the manufacturer's instructions shall be followed in relation to preparing for use, making allowance for warm-up time and performing preliminary user adjustments.

7.6.2 During tests, user adjustments may be repeated at the intervals prescribed by the manufacturer or at any suitable interval if such user adjustments do not affect the error to be checked. The mechanical zero of analogue indicators may be adjusted whenever necessary, except when measuring zero drift.

7.6.3 User adjustments shall be performed when limits of error have been expressly stated to be valid only after user adjustment. Measurements shall then be made immediately after such a user adjustment so that drift (if any) will not affect them.

7.6.4 On request, the manufacturer shall state whether it is permissible to replace the batteries by an external d.c. supply, when making electrical tests under reference conditions on equipment operated by replaceable batteries. This supply should be equivalent to the batteries in voltage and impedance

7.7 Reference Operating Conditions

7.7.1 In creating reference conditions for use in the compliance testing described here the reference ranges for temperature, relative humidity and air pressure should preferably be taken from IS 9000 (Part 1).

7.7.2 The reference range for any other influence quantity shall be the range which contains no value having any significant effect on the error of any performance characteristic.

NOTE — For most practical purposes, this range can be understood to contain no value which increases the error by more than 10 percent of the intrinsic error found in the absence of the influence quantity.

7.7.3 On request, the manufacturer shall state the reference value or reference range, he uses for any influence quantity which he specifies for his product.

7.7.4 For guidance, some influence quantities which may affect the performance of measuring equipment are listed below:

a) *Climatic influence quantities*
   1) Ambient temperature.
   2) Relative humidity of the air.
   3) Barometric pressure (altitude).
   4) Heating effect due to solar radiation.
   5) Velocity of the ambient air.
   6) Sand and dust.
   7) Salt mist.
   8) Contaminating gases or vapour.
   9) Liquid water (condensation, fog, drip and splash water).
   10) Icing.
   11) Fungi.

b) *Mechanical influence quantities*
   1) Operating position.
   2) Ventilation.
   3) Vibration.
   4) Mechanical shock.
   5) Sound pressure.

c) *Supply influence quantities*
   1) Voltage.
   2) Frequency.
   3) Distortion factor.
   4) Transient disturbances.
   5) Source impedance of mains supply.
   6) Potential of the protective conductor.
   7) Ripple of d.c. supply.

d) *Fields and radiations as influence quantities*
   1) Electric fields.
   2) Magnetic fields.
   3) Electromagnetic fields.
   4) Ionizing radiations.

ANNEX A

(*Clauses* 4.4 *and* 7.2.5)

STATISTICAL CALCULATION OF OPERATING ERROR

In this Annex, intrinsic errors and variations are referred to as partial errors.

A-1 RECOMMENDED FORMULAE

Formulae (1) and (2) assume that the partial errors are statistically independent.

Formula (1) : this is for use where the limits of the partial errors (T_i) are asymmetrical with respect to zero.

$$E_{l,u} = \sum_{i=1}^{n} \overline{T}_i \pm 2\sqrt{\sum_{i=1}^{n} (s_{T_i})^2}$$

where

E_l = lower limit of operating error

E_u = upper limit of operating error

$\overline{T} = \dfrac{(T_u + T_l)}{2}$

$\overline{T}$ = arithmetic mean value

$(s_T)^2 = \dfrac{(T_u + T_l)^2}{12}$

s = (experimental) standard deviation

T_l = lower specified limit of a partial error

T_u = upper specified limit of a partial error

i = index number of the partial error

Formula (2) : this simpler form of the formula can be used if the limits of the partial errors are symmetrical with respect to zero, that is:

$$|T_u| = |T_l| = T_m$$

$$E_{l,u} = \pm 1.15\sqrt{\sum_{i=1}^{n} T^2_{m_i}}$$

NOTE — Formula (2) is related to the often applied quadratic summation of the partial errors in calculating a total error. It differs only by the factor 1.15. This factor ensures that both formulae (1) and (2) calculate the limit values with the same small possibility of exceeding these values.

A-2 BACKGROUND FOR CALCULATION

Every partial error can be seen as a random variable T, which does not exceed its stated tolerance limits T_l and T_u. For most of the partial errors, this is the only sure item of knowledge because, during the manufacture of measuring equipment, only these tolerance limits serve for test criteria with reference to the performance of the equipment.

Owing to the aforementioned situation, the assumption that the partial error T appears with uniform probability at every place within the interval $T_u - T_l$ is essentially more pessimistic than the assumption that T is subject to a normal distribution. Furthermore the former assumption is more realistic than the assumption that T is only located at the limits of the interval.

With this assumption of uniform distribution, and using the rules of statistics, further relationships can be developed and the mean value and standard deviation of every partial error can be calculated. Thereupon, the parameters of the distribution of operating error can be calculated. According to the central limit theorem of statistics, the random sum of the intrinsic error and all variations included in the operating error is an asymptotic normal distribution. A pre-assigned probability (here 95 percent) in conjunction with the normal distribution can be employed to form a confidence interval that, on average, includes 95 percent of all values of the random variable operating error. This is accomplished by the formulae given in **A-1**.

In cases where a pre-assigned probability other than 95 percent is required, the factor f which equals 2 in the second term of formula (1) can be changed. Some examples as follow:

Probability of not Exceeding Limits percent	*Factor* f	*Probability of Exceeding Limits percent*
90	1.7	10
95	2.0	5
99	2.6	1

A-3 SIGNIFICANCE OF THE PROBABILITY OF EXCEEDING THE LIMIT VALUES

In the rules of **A-1** for calculating the operating error, there is approximately a 5 percent probability of exceeding the calculated limit values when the assumption is met that the measured intrinsic error and variations are really uniformly distributed. However, the method of series production does not normally allow such a distribution. Because of these facts, there arises the question of the true probability of exceeding the limit values. This question cannot be answered. Only a certain amount of information appears to be sure: one population can be considered as the measuring conditions within the operating conditions and a second population can be considered as measuring instruments of the same type for which the stated limits of operating error are valid.

If from these two populations for a measurement a random choice is made, both for the measuring conditions as well as for the equipment, then the probability of exceeding the limit values of the operating error that occurs is considerably less than 5 percent. If the choice for measuring conditions is not random, but preference is given instead to choosing measuring conditions that avoid extreme values, then the probability of exceeding the limit values is reduced further still. If measurements are performed predominantly under extreme measuring conditions, then the 5 percent value can be reached or even exceeded.

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